Phase I Project Summary

Firm: MicroXact, Inc.
Contract Number: NNX10CB68C
Project Title: Ultraefficient Thermoelectric Devices

Identification and Significance of Innovation: (Limit 200 words or 2,000 characters whichever is less)

Thermoelectric (TE) devices already found a wide range of commercial, military and aerospace applications. Not only do TE devices have proven long-life performance reliability, withstand rigorous vibration, and are relatively insensitive to radiation and other environmental factors. However, commercially available TE devices offer limited conversion efficiencies, well below the fundamental thermodynamic (Carnot) limit due to limited Figure of Merit (ZT). While a number of new high-ZT materials have been proposed and/or demonstrated in the lab over the last decade, none of such materials was used in commercial devices due to the expensiveness of fabrication techniques required.
The team of MicroXact Inc., Virginia Tech and Old Dominion university proposed to develop a revolutionary ultrahigh efficiency thermoelectric material in the form of three-dimensional "wells" of Bi_2Te_3/Sb_2Te_3 Quantum Quantum Well Superlattices (QDS) fabricated by a conformal coating of macroporous silicon (MPSi) pore walls with Atomic Layer Deposition (ALD) technique. The Bi_2Te_3/Sb_2Te_3 QWSs exhibit very high ZT values. However, the thicknesses of fabricated QDS samples were limited to 100s of nm. With the proposed approach the QWSs with thickness from 10s to 100s of um will be cost-effectively fabricated by depositing only few 100s of nm QWS coating of MPSi pore wall.

Technical Objectives and Work Plan: (Limit 200 words or 2,000 characters whichever is less)

Phase II project objectives were:
Objective 1: Design the 2nd Generation ultraefficient TE material and device.
Objective 2: Demonstrate ALD deposition of high-ZT Bi_2Te_3/ Sb_2Te_3 superlattice on porous silicon template.
Objective 3: Performance verification.
Objective 4: Finalize commercialization and transition to manufacturing strategy.

Work proceeded through the following tasks:
Task 1: Improve the theoretical model of the proposed material and design 2nd generation ultraefficient TE material (MicroXact).
Task 2: Improve the process of macroporous silicon fabrication with appropriate pore morphology and fabricate sufficient quantity of MPSi templates (MicroXact).
Task 3: Develop Bi_2Te_3/Sb_2Te_3 ALD deposition process and fabricate a number of device wafers (Old Dominion University).
Task 4: Characterize developed materials and devices (Virginia Tech).
Task 5: Develop thermoelectric generator prototype and demonstrate >15% efficiency (all the team).
Task 6: Finalize commercialization and transition to manufacturing strategy (MicroXact)

Technical Accomplishments: (Limit 200 words or 2,000 characters whichever is less)

An accurate and thorough model of novel thermoelectric device was improved. The macroporous silicon template fabrication was perfected. Atomic deposition of Bi_2Te_3, Sb_2Te_3 and Bi_2Te_3/Sb_2Te_3 superlattice was developed to the advanced level, resulting in large Seebeck coefficient and low thermal conductivity of superlattices. In parallel, electroless plating on high aspect ratio structures was demonstrated. Wafer scale electrochemical eALD system was developed and demonstrated, eALD of Bi_2Te_3, Sb_2Te_3 and Bi_2Te_3/Sb_2Te_3 superlattices is perfected to adequate level. Thick porous Si layers with significantly lower thermal conductivity at the same electrical conductivity were developed and demonstrated. 20um thick SiGe superlattice was developed and demonstrated. Prototype TE generator was fabricated. This provides a solid foundation for future commercialization of ultraefficient thermoelectric materials and devices. MicroXact also identified both the near term and long term applications and developed a concept of a commercialization plan for the proposed thermoelectric material and devices.

NASA Application(s): (Limit 100 words or 1,000 characters whichever is less)

The largest immediate NASA application of the proposed ultraefficient thermoelectric materials and devices is thermoelectric generators. The advantages of the proposed technology (unmatched efficiency combined with the small size and low weight) would provide the competitive advantage to MicroXact sufficient for successful market penetration. Other potential NASA applications include potential powering small devices from human thermal energy and refrigeration. Due to the unique benefits the proposed materials and devices are expected to penetrate these and other NASA applications. The proposed concept is expected to cause a significant impact on the cost, safety and reliability of future NASA missions.

Non-NASA Commercial Application(s): (Limit 200 words or 2,000 characters whichever is less)

The developed ultraefficient thermoelectric materials and devices are expected to find applications in such fields as electronic device cooling (microprocessors, focal plane arrays, etc.), food storage/processing (wine cellars, Freon-free refrigerators), automotive and aviation industry (to enhance the fuel consumption). Due to the unique performance expected from proposed materials and devices all these markets can be potentially addressable with the proposed technology. The most promising market for initial penetration is believed to be the electronic component cooling market, where the benefits of the proposed technology (high efficiency combined with potentially reduced size) would provide the largest competitive advantage.

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